RELATIVE SUSCEPTIBILITY OF PONDEROSA PINES TO BARK-BEETLE ATTACK

By F. P. KEEN[1]

RECENT heavy killing of ponderosa pine in the Pacific states through attacks of various bark-boring beetles, principally the western pine beetle (*Dendroctonus brevicomis* Lec.), has brought to the forefront the important question of controlling or eliminating such losses. In the mature and over-mature ponderosa pine stands of California, Oregon, Washington, and Idaho during the past two decades, these beetles, collectively referred to as "pine beetles", have caused an annual timber loss which has run into billions of board feet. Some areas have lost such high percentages of merchantable stands as to become valueless for logging. Over many areas the annual mortality has so greatly exceeded growth as to result in a serious depletion of mature timber reserves. Such losses as these raise a serious question as to the feasibility of profitable sustained-yield timber production in the pine region, and discourage private timber operators from leaving any merchantable volume in the woods if it can be profitably liquidated at the time of logging.

Both from the immediate viewpoint of timber salvage and from the forestry objective of a satisfactory silvicultural management of ponderosa pine stands, one of the first requirements in the solution of the pine beetle problem is a knowledge of what type of tree presents the greatest risk of beetle attack. Once the type of tree most likely to be killed can be recognized with a fair degree of certainty, it is possible to make partial cuttings of beetle-susceptible trees, either for the purpose of salvaging valuable high-risk trees before they are damaged by beetle attack or for the silvicultural objective of reducing mortality and increasing net growth.

During the last decade the relative susceptibility of different types of ponderosa pine to pine-beetle attack has received considerable study by silviculturists and forest entomologists. These studies have revealed that the risk of being killed by western pine beetles is distinctly greater for trees of certain types than it is for other trees in the same stand. In general, the trees more susceptible to attack are the weaker, less vigorous individuals and, to a certain degree, those more advanced in age. The problem, therefore, is one of recognizing the combination of characters which indicates susceptibility.

Dunning, (2) in the study upon which he based his tree classification, found that in terms of basal area the probable insect loss was greatest for his classes 7, 5, and 4; and that in terms of number of trees it was greatest for classes 4, 2, 5, and 7, in that order. Person (4) reached similar conclusions, and found that the beetles showed a decided preference for slow-growing trees, for trees in the diameter range between 20 and 30 inches, and for those growing on the poorer sites. This selection, he found, was less marked under decreasing epidemic conditions than under endemic or increasing epidemic conditions. Further extensive studies made by the writer from 1927 to 1932, in connection with western pine beetle surveys in southern Oregon and northern California, repeatedly showed the same selective tendencies. A preliminary summary

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of these studies has been reported by Meyer (3).

During the course of these field studies it became evident that marked differences in susceptibility existed within some of the Dunning tree classes. It even appeared probable that, in some cases, these differences might be greater for certain types of trees within a single class than for different tree classes. In order to isolate the specific characters that were most important in indicating susceptibility, it seemed desirable, therefore, to set up a more detailed classification, with a large number of small, homogenous, easily recognized tree types, which could be used in the field for further study.

Description of the Bark-Beetle Susceptibility Classification

The tree classification which was adopted for this purpose, and which may be called the "bark-beetle susceptibility classification", is illustrated in Figure 1. It is based to a large extent upon the same considerations of age, dominance, and vigor which Dunning recognized as forming the basis for his seven classes. The new classification uses these same basic characteristics to regroup all ponderosa pines into a larger number of classes. The two characteristics of age and vigor are given primary importance. Four age groups are recognized, designated 1 to 4; and four degrees of crown vigor, designated A to D. Combining these two major groups gives a series of 16 classes, covering all types of trees found in a stand.

The tree class descriptions to a large extent follow those defined by Dunning, but they have been modified to apply more specifically to the mature ponderosa pine forests of average site IV quality in southeastern Oregon and northeastern California. Although trees throughout the pine region may be similarly grouped into 16 age and vigor classes, the class descriptions will have to be somewhat modified to apply in other localities and on poorer or better sites.

Age Groups

Trees are first divided into four age groups—young, immature, mature, and overmature. In average site IV ponderosa pine stands of the Pacific region, the characteristics of these age groups are as follows:

1. YOUNG. *Age:* Usually less than 75 years. *D.b.h.:* Rarely over 20 inches. *Bark:* Dark grayish-brown to black, deeply furrowed, with narrow ridges between the fissures. *Tops:* Usually pointed, with distinct nodes. *Branches:* Upturned and whorls.

2. IMMATURE. *Age:* Approximately 75 to 150 years. *D.b.h.:* Rarely over 30 inches. *Bark:* Dark reddish brown, with narrow, smooth plates between the fissures. *Tops:* Usually pointed, but with nodes indistinct. *Branches:* Mostly upturned and in whorls for upper half of crown.

3. MATURE. *Age:* Approximately 150 to 300 years. *D.b.h.:* Rarely over 40 inches. *Bark:* Light reddish brown with moderately large plates between the fissures. *Tops:* Pyramidal or rounded. *Branches:* Upturned near top, those of middle crown horizontal, lower ones drooping; whorls incomplete.

4. OVERMATURE. *Age:* More than 300 years. *D.b.h.:* Usually of large diameter. *Bark:* Light yellow, the plates usually very wide, long, and smooth. *Tops:* Usually flat and making no further height growth. *Branches:* Mostly drooping gnarled, or crooked.

In dividing trees into these four general age groups, more weight should be given to relative maturity, or what might be called "physiological age", than to exact age as indicated by annual rings. Some trees growing under favorable conditions, particularly on good sites, retain

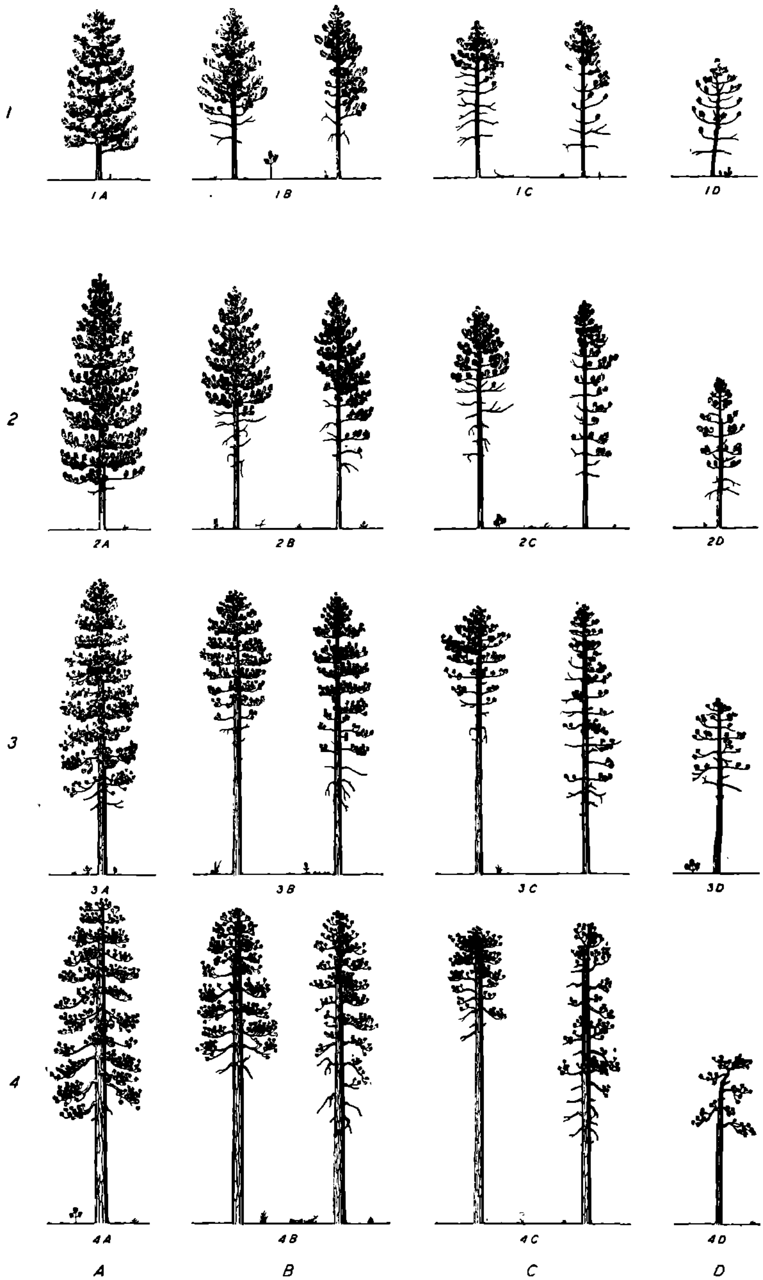

Fig. 1.—A ponderosa pine tree classification chart for comparison of bark-beetle susceptibility classes based on age and vigor.

their youthful appearance and vigor much longer than do trees that have been forced to struggle against unfavorable environmental conditions, such as those on poor sites. Since trees must be judged largely on the basis of external appearances, those having all the outward characteristics of a given age group should be classed in that group, even though they are actually somewhat younger or older than the designated age limits.

The distinction between Groups 1 and 2 is based largely on color and roughness of bark. While both are sometimes called "bull pines" or "blackjacks," only the Group 1 trees have the rough black bark which is so typical of juvenile growth. The change from Group 1 to Group 2 takes place at approximately 75 years of age in the site IV stands of southern Oregon. At that age there is a slowing down in the rate of height and diameter growth, narrow plates appear between bark fissures, and the bark starts to take on the reddish-brown color characteristic of maturity. Suppression in the seedling stage may greatly extend the period of juvenile growth and advance subsequent age limits. The distinction between mature and overmature trees, Groups 3 and 4, is more difficult to recognize, and involves character of crown as well as bark differences.

Vigor Groups

In judging the relative vigor of different trees of a given age, the size of crown and abundance of foliage are probably the best outward indicators. Therefore, each age group is further subdivided into four sub-groups based upon relative crown vigor. These are designated by letters A to D as follows:

A.—Full, vigorous crowns, with a length of 55 per cent or more of the total height, and of average width or wider; foliage usually dense; position of tree isolated or dominant (rarely codominant); diameters large for age.

B.—Fair to moderately vigorous crowns with average width or narrower, and length less than 55 per cent of the total height; either short wide crowns or long narrow ones, but neither sparse nor ragged; position, usually codominant but sometimes isolated or dominant; diameters above average for age.

C.—Fair to poor crowns, very narrow and sparse or represented by only a tuft of foliage at the top; foliage usually short and thin; position usually intermediate, sometimes codominant, rarely isolated; diameters below average for age.

D.—Crowns of very poor vigor; foliage sparse and scattered or only partially developed; position suppressed or intermediate; diameters decidedly subnormal, considering age.

By combining the four age sub-groups with the four sub-groups of crown vigor a total of 16 classes was obtained which could be analyzed for relative susceptibility.

According to definition, the comparison between the expanded classification and Dunning's classification is as follows:

Classes defined by Dunning	Bark-beetle susceptibility classes
1	1A, 2A
2	1B, 2B
3	3A
4	3B, 3C
5	4A, 4B, 4C
6	1C, 2C, 1D, 2D
7	3D, 4D

Or, in reverse order:

Bark-beetle susceptibility classes: *Age group*	*Vigor group*	Dunning's classes
1	A, B, C, D	1, 2, 6, 6
2	A, B, C, D	1, 2, 6, 6
3	A, B, C, D	3, 4, 4, 7
4	A, B, C, D	5, 5, 5, 7

Relative Susceptibility of the Tree Classes

In order to determine which of these tree classes were particularly favored by the beetles in making their attacks, a study was started in 1928 in connection with western pine beetle surveys in virgin ponderosa pine stands of southern Oregon and northern California. During a four-year period, 1928 to 1931, a total of 27,465 beetle-killed trees on approximately 15,000 acres of sample plots were classified under the bark-beetle susceptibility classification. During the same period a mechanically selected sample of 22,428 living trees was similarly classified for comparison. In 1932 a 10 per cent cruise of the plots was made, and the total number of surviving trees was determined, to which was added the number of trees killed by beetles during the previous four-year period in order to reconstruct the original stand as of 1928.

The apportionment of the beetle-killed trees between the different tree classes as compared with the distribution of these classes in the original stand is shown in Table 1. The mortality ratio, which has been obtained by dividing the percentage occurrence of beetle losses in a given class by the percentage occurrence of that class in the original stand, gives a measure of relative susceptibility. If, for instance, 9 per cent of the killed trees are found in a certain class, and 9 per cent of the original stand is also found in that class, the ratio will be 1, which indicates no particular preference. Ratios above 1 indicate that such types are more frequently found among the killed trees and are susceptible, while ratios below 1 indicate corresponding resistance.

The results given in Table 1 represent the average condition found in the region sampled during the period of this study. The stands sampled were all virgin ponderosa pine ranging from site III to site V, with volumes of from 6,000 to 22,000 board feet per acre. Pine beetle infestation varied during the four-year period from a highly epidemic condition, with a loss in one year on one 640-acre plot of 880 board feet per acre, to a low endemic kill on another plot of 70 board feet per acre. The average loss on all

TABLE 1

RELATIVE BARK-BEETLE SUSCEPTIBILITY OF VIRGIN PONDEROSA PINES IN THE KLAMATH REGION SOUTHERN OREGON-NORTHERN CALIFORNIA

Tree class		Total stand[1] per 1,000 acres		Trees killed in 4 years[2] per 1,000 acres		Average per cent trees killed	Mortality	Relative
		Trees	Per cent	Trees	Per cent	Per year	ratio	susceptibility
1	A	1,983	8.8	24	1.5	0.3	0.17	16
	B	1,160	5.1	40	2.5	0.9	0.49	12
	C	548	2.4	62	3.8	2.8	1.58	5
	D	51	0.2	8	0.5	3.9	2.50	1
2	A	1,987	8.8	45	2.8	0.5	0.32	15
	B	2,181	9.7	153	9.5	1.7	.98	11
	C	1,409	6.3	229	14.1	4.1	2.24	2
	D	344	1.5	29	1.8	2.1	1.20	8
3	A	1,940	8.6	56	3.5	0.7	0.41	14
	B	2,387	10.6	189	11.7	2.9	1.10	10
	C	1,840	8.2	212	13.1	2.9	1.60	4
	D	674	3.0	65	4.0	2.4	1.33	6
4	A	1,997	8.9	70	4.3	0.9	0.48	13
	B	2,242	10.0	188	11.6	2.1	1.16	9
	C	1,290	5.7	200	12.4	3.9	2.18	3
	D	489	2.2	47	2.9	2.4	1.32	7
Total		22,522	100.0	1,617	100.0	1.8		--

[1]Total living pine stand as of 1928, based on a 10 per cent cruise of 15,000 acres of sample plots

[2]Based on 100 per cent cruise of beetle mortality on the same sample plots during the 4-year period 1928-1931.

plots during the four-year period was approximately 300 board feet per acre per year.

The mortality ratios represent the general averages found under all of the above conditions. They should not be considered as fixed constants, but rather as a sliding scale of values which vary for different stands and intensities of infestation. While the present ratios are undoubtedly significant of the general trend in virgin ponderosa pine stands of this region, quite different ratios may be expected in reserve stands left after different degrees of cutting and in forests placed under management.

On the other hand, the relative susceptibility ranking of the different tree classes does not change appreciably under varying conditions. When infestation is low, the selective tendencies are more pronounced and a greater proportion of loss occurs in the more susceptible tree classes at the top of the scale. As the mortality rate increases, more tree classes are included. Under severe epidemic conditions, especially on the poorer sites, nearly all classes of trees, except the most resistant types, are apt to sustain a nearly equal proportion of the total loss.

It will be noted that in each age group susceptibility increases with a decrease in crown vigor (A to D), except that in the three older age groups the C crowns appear to be more susceptible than the D crowns. While the number of cases represented by the D crowns may not be sufficiently large to substantiate this point, it has been observed in the field that the very poorest trees, as represented by the D crowns, are often ignored by the beetles, while neighboring trees of better vigor are taken. It may be that trees of this class offer too little nourishment to the beetles to make them attractive.

A comparison of the relative susceptibility by comparable crown classes for the four age groups brings out the point that there is a gradual increase in risk with advancing age (1 to 4). It will be noted, however, that the difference in age between one class and the next is not nearly so important in determining susceptibility as a difference in crown vigor class. For instance, an old, overmature tree of Class 4A, while more susceptible than younger trees with A crowns, is not nearly as likely to be killed as an immature tree of Class 2B or 2C. Such a veteran dominant tree usually has crowded out all of the trees around it and is well able to continue resisting the elements and insect attacks for a few more years, as it has done for the past three centuries or more. A young intermediate or codominant tree struggling for its place in the stand is much more likely to succumb within the same period of time.

The present study shows that in the ponderosa pine stands of this region bark beetles are carrying on a natural selection which thins the stands of the weaker individuals and favors the survival of the dominants. They are Nature's silvicultural agents, which relieve the pressure of severe tree competition or of critical growth conditions and tend to preserve a natural balance between growing stock and available supplies of plant food and soil moisture. Since all trees with C and D crowns are susceptible to pine-beetle attack, with B crowns intermediate and with A crowns resistant, it is apparent that these beetles are effecting a type of tree elimination which is comparable to an improvement thinning. Year by year they are making "thinnings from below" and a "selection cutting" of the older age classes. On poor sites this elimination during epidemic periods sometimes approaches a clear cutting. This thinning process is largely responsible for the spacing found in a natural forest. The beetles show a marked tendency to concentrate their attacks upon trees growing in groups—probably because of the severe competition which group-wise trees may experience, especially during periods of drought.

Application to Marking Practice

To illustrate how the results of this study may be of value in connection with marking virgin ponderosa pine stands for salvage or selection cuttings, it may be of interest to examine Table 2, in which the average stand structure on 15,000 acres of site quality IV ponderosa pine in southern Oregon is used as a basis. In this table the merchantable stand is subdivided into groups according to relative susceptibility and value.

For practical purposes, the 16 tree classes are arranged in three general susceptibility groups as follows:

Susceptible Types.—This group includes all trees with C and D crowns, and, according to relative risk from higher to lower, the tree classes belonging here appear in the following order: 1D, 2C, 4C, 3C, 1C, 3D, 4D, 2D.

Intermediate Types.—This group takes in trees with B crowns in the three older age classes. From higher to lower risk in this group, the order is as follows: 4B, 3B, 2B.

Resistant Types.—This group, on the average, is resistant to beetle attack and therefore comprises the best trees to leave in the reserve stand as far as pine-beetle risk is concerned. From the poorest risk to the best, these classes are as follows: 1B, 4A, 3A, 2A, 1A. All except class 4A are types of trees which are normally left under present Forest Service marking policy.

In Table 2 trees 10 inches or more in diameter are arranged by classes according to these three susceptibility groups, and further, according to their relative

Table 2

General susceptibility and value grouping of virgin ponderosa pine stand in sample area of 15,000 acres in southern Oregon

Tree class	Average diameter (inches)	Average volume (board feet)	Percentage of stand volume: Tree class	Group	Type
SUSCEPTIBLE TYPES. TREES OF HIGHEST BEETLE RISK					
Trees usually of high value					
4 C	28	1,280	9.1		----
3 C	21	540	5.3	14.4	----
Trees usually of low value					
2 C	16	160	1.1	----	----
4 D	18	300	1.0	----	----
3 D	14	140	0.5	----	----
2 D	12	70	0.1	2.7	----
Unmerchantable					
1 C	12	60	0.2	----	----
1 D	10	30	----	0.2	17.3
INTERMEDIATE TYPES. TREES OF FAIR RISK UNDER AVERAGE CONDITIONS					
Trees usually of high value					
4 B	32	1,790	23.0	----	----
3 B	26	930	12.4	35.4	----
Trees usually of low value					
2 B	19	300	3.7	3.7	39.1
RESISTANT TYPES. TREES REPRESENTING GOOD RISKS					
Trees usually of high value					
4 A	35	2,200	25.5	----	----
3 A	27	1,100	11.9	37.4	----
Trees usually of low value					
1 B	14	100	0.7	----	----
2 A	20	370	4.3	----	----
1 A	14	100	1.2	6.2	43.6

commercial value as indicated in a study by Anderson (1) for comparable tree classes.

If the primary purpose of a marking is to salvage valuable trees which are likely to be killed before they are reached in the normal course of logging, then only such classes of beetle-susceptible trees as will yield a profit need be included. Trees of no value may be left in the woods to run the risk of beetle attack, for even if they are killed no present convertible value has been lost. On average sites or better, Classes 4C and 3C, which in the stand illustrated in Table 2 contain 14.4 per cent of the volume, would be given first consideration. A few of the other C- and D-crown trees might be taken when accessible. If the site were poorer than average, then trees of Classes 4B and 3B, representing an additional 35.4 per cent of the stand in trees of intermediate risk but of high value, should be included.

Such a plan of salvage would necessitate covering large areas with a light cut in a short space of time. Economic considerations will decide to what extent such a plan is feasible and how large a volume will have to be removed to make the operation profitable. Unless the cut is heavy enough to open up the stand and stimulate growth in the reserve, the effect in reducing the threat of beetle infestations is likely to be negligible.

If, on the other hand, the primary purpose of a marking is to forestall pine-beetle outbreaks and reduce mortality rates, then all the more susceptible types of trees likely to foster infestations should be removed and the stands sufficiently thinned to give noticeable release and growth stimulation to the reserve. This usually will involve a much heavier cut, and it will not be possible to cover an area as quickly as with a salvage cutting. In average site IV stands, the minimum requirement would be the removal of the more susceptible types, which include all trees of classes C and D. On poorer than average sites, trees of intermediate risk, the older trees with B crowns, would also need to be taken.

While it seems reasonable to suppose that a stand which has been thinned of the more susceptible trees should be in better shape to resist bark-beetle epidemics, there is no proof as yet that such stands will be immune to further losses. During periods of bark-beetle epidemics trees of all classes may be killed, with little regard to apparent vigor. Also, on poor sites, in "fringe type" timber, and on areas suffering from the effects of drought, all types of trees are reduced in vigor and resistance to pine-beetle attack, and tend to become nearly equal in susceptibility. There are many examples to show that on such problem areas it is futile to leave as a reserve any but the youngest and most vigorous trees.

It will be noted that the marking suggested for the purpose of preventing beetle outbreaks is comparable to present marking practice in the ponderosa pine forests of the National Forests and Indian reservations of this region. Under this more or less standard system, all of the more susceptible and intermediate types of trees (Table 2) are marked for cutting, as well as beetle-resistant trees of Class 4A. A cutting under this system removes approximately 80 to 85 per cent of the stand and so nearly eliminates all types of beetle-susceptible trees on the area cut over that the problems of salvaging additional values or of further reducing the threat of beetle loss are usually solved. During the last decade, however, on poor sites and in fringe-type timber, the beetle losses to reserve stands cut under this marking practice have been such as to raise considerable doubt as to its adequacy under these conditions.

The cutting of all merchantable timber, such as is the practice on many private operations, of course eliminates for a good many years further trouble from the western pine beetle. Such cuttings, if protected from fire, produce even-aged stands, often with satisfactory stocking, but with the prospect of a second timber crop projected far into the future. For certain problem areas, such as those mentioned above, a heavy cut is undoubtedly the only practical method of eliminating serious beetle losses in reserve stands and of obtaining substantial net annual growth.

Silvicultural management of our ponderosa pine forests should eventually lead to the solution of the present pine-beetle problems. Improvement of growth conditions and the reduction of mortality are such closely related phases of timber management that the measures necessary to accomplish one are certain to have a beneficial effect upon the other. The types of trees which should be cut in order to improve growth in the residual stand are also those which should be removed in order to reduce mortality. Although forest management may not eliminate all future bark-beetle troubles, it is at least a step in the right direction of improving the chances of ponderosa pine stands to escape such injury.

In actual practice, economic considerations will often dictate the extent to which silvicultural and bark-beetle hazard-reduction measures may be applied. Because of their low commercial values, it will often not be feasible to remove all of the small beetle-susceptible trees which it might be desirable to cut from a strictly entomological standpoint. The final solution of any marking problem will of necessity be determined by weighing the importance of growth, mortality, and economic factors, keeping always in mind the ultimate objective of continuous profitable forest production.

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